GRID REGIONALIZATION IN THE WEST: RELIABILITY BENEFITS FROM INCREASED COOPERATION IN ELECTRICITY MARKETS AND OPERATIONS

August 2024 By Mareldi Ahumada-Paras, Michael Mastrandrea, and Michael Wara

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EXECUTIVE SUMMARY

In recent years, parts of the U.S. electricity grid have experienced increasing impacts from weather and climate-related extreme events that have disrupted system operations, triggered emergency responses, and motivated stakeholders to make substantial changes to planning strategies. In the West, extreme heat events combined with severe drought that limits availability of hydropower have proven particularly challenging for grid operators to manage.

Balancing Authorities (BA) are the entities responsible for ensuring electricity supply and demand balance – that is, bulk power system (BPS) reliability – within their service territory of the grid. Each BA can meet their needs by either dispatching generating units within their footprint, establishing forward contracts, or trading energy with neighboring BAs by participating in wholesale markets. In the western grid, called the Western Interconnection, all BAs at times use and to varying degrees rely on electricity imports to meet their demand primarily due to operating system efficiency and the economic benefits of participating in wholesale markets. However, when the system is most stressed because of extreme weather events that span across a large area, availability of resources in wholesale markets may be compromised, thus reducing access to imports and increasing the risk of not meeting demand. In such situations, operators in each BA make decisions based on imperfect information and rely on best practices and operator experience to overcome challenges in real-time. This uncertainty in the system poses a higher risk of failing to meet reliability and security standards and potentially leads to local or widespread power outages. As operations have evolved throughout the growth and structural evolution of the electrical grid, so have the responsibilities and organizational structures that define each BA. In today's BPS operations, the most comprehensive structure is a regional transmission organization (RTO) having oversight of centralized unit commitment, economic dispatch, coordinating over a larger, multi-utility footprint and planning transmission system expansion. Naming conventions have also varied with time; we refer to an Independent System Operator (ISO) and an RTO as the overarching terms for cooperation areas comprised of multiple BAs. For the purposes of this study, we refer to ISO/RTO as entities that maintain operational and planning responsibilities within their region, without specifying a particular structure or governance framework. The latter falls outside the scope of this work and requires the ongoing consideration of decision makers who must balance multiple policy priorities.

This study evaluates shifts in utilization of generation, imports, and exports as we assign different cooperation regions in the West. We do this to illustrate the potential benefits to operations and reliability - under stressed grid conditions created by extreme heat and drought - of expansion and adaptation of existing markets, like the Extended Day-Ahead Market (EDAM), into a larger ISO/RTO. EDAM is a day-ahead market proposed by a number of western BAs and recently approved by the Federal Energy Regulatory Commission (FERC) as a component of the California ISO's (CAISO) tariff. EDAM will become operational across its initial footprint in 2026. Several recent analyses have evaluated the potential economic benefits of increased cooperation among western BAs, but none have focused on the potential reliability impacts to date. These studies have generally shown real but modest economic benefits from a shift to organized regional electricity markets with larger footprints.

Simulating reliability impacts with power system optimization models is challenging because these models assume perfect information to optimize dispatch across all western BAs and optimization across the entire Western Interconnection footprint. In other words, they behave as if an RTO exists, with some limited economic frictions. In the real world, especially during stress events, system operations can divert substantially from the optimal outcome due to incomplete information, risk aversion by individual BAs, and other factors. Because of this challenge in simulating stress conditions using these models, we interpret our results as illustrative and directional rather than a precise estimate of the reliability benefits of a larger, ISO/RTO footprint.

Despite these challenges, we show that growing the footprint of an organized market for electricity in the West has the potential to substantially reduce risks to reliability under extreme heat scenarios derived from the September 2022 California heat event. Our case study of simulated extreme stress conditions shows a 40% decrease (from 25% down to 15%) in West-wide hours at risk following expansion from an ISO/RTO with a footprint similar to EDAM to the entire Western Interconnection. Simulated unserved energy is also more than cut in half (from 1901 to 877 GWh). In other words, by creating and expanding an ISO/RTO beyond the current EDAM members (detailed in appendix A), our work suggests that western BAs can substantially reduce the risks of unserved energy and rotating outages. This work thus complements earlier work on economic benefits of a western ISO/RTO and adds an additional dimension to the ongoing stakeholder efforts to broaden and enhance coordination of electricity operations in the West. Further studies and analysis are needed in order to fully understand all the potential benefits and costs of creating an ISO/RTO that spans across multiple states in the West.

Our results also lend an additional dimension of support for the reforms being undertaken to create a more equitable and independent governance structure for the EDAM and the Western Energy Imbalance Market (WEIM) via changes to the CAISO tariff, as well as the West-Wide Governance Pathways Initiative Phase I and Phase II efforts. Given the growing impacts of climate change on extreme heat events that translate directly into grid stress events, our results also indicate the value to all parties of greater integration that can only result from shared and equitable governance structures that facilitate greater sharing of resources. Our work is intended to motivate those efforts by providing a more complete picture of potential benefits to energy market regionalization that should be balanced against potential risks of such shared governance.

INTRODUCTION

The electric grid is a true marvel of human ingenuity, perseverance and care – the largest single machine that humans have ever created. Ingenuity was required to create it. Perseverance to keep it operating as reliably as it does in the United States. And care to ensure that reliable operations are also safe and affordable. All three are needed now, to ensure that reliability is maintained as we transition from a grid primarily fueled by fossil fuels to one that is heavily reliant on renewable resources, while we also contend with the rising impacts of climate-related extremes including wildfires and extreme heat. Operation and planning of the electrical grid have adapted, and continue to adapt, to meet present day needs, given that electricity is essential to a safe and prosperous modern society.

In recent years, parts of the Western Interconnection have experienced extreme events (particularly heat events) that have stressed system operations, triggered emergency responses and prompted stakeholders to make substantial changes to planning strategies. In 2020, a west-wide heat event resulted in rotating outages on August 14th and 15th in CAISO's territory. In 2021, drought conditions exacerbated the Bootleg fire in Oregon and disrupted transmission lines, hindering the energy interchange capacity between Oregon and California during periods of extreme heat. And in 2022, high temperatures created a record peak load of 52,061 MW in CAISO footprint. This peak load broke records from the early 2000s that most thought would never again be approached in California because of the massive growth in rooftop solar, which reduces peak demand for grid supplied energy. The CAISO grid was stressed to the point of the Governor's Office of Emergency Services calling upon the population via text message to decrease their consumption in order to avoid outages.[1] Once again, in Summer 2024, high temperatures in addition to intensified drought conditions[2] made Pacific Northwest system operators run the system at stress conditions.

Due to such challenges, and the expectation that they are likely to intensify in the future as the western US climate becomes hotter and drier, stakeholders across the Western Interconnection are responding by proposing initiatives that would consolidate efforts and modify markets, planning, and operations in different regions with the overall goal of increased cooperation and collaboration in meeting electricity demands across the West. This kind of regional cooperation has long been a hallmark of western electricity planning, despite the large number of entities in the region responsible for system planning and operations. But increased coordination in the West is now more beneficial than ever. In addition, transmission investments and expansion, critical for unlocking the potential value expected through the Inflation Reduction Act,[3] will need to be planned across boundaries, requiring additional cooperation in both planning and cost allocation. The Western Electricity Coordinating Council (WECC) in its most recent Western Assessment of Resource Adequacy (WARA) recommends that the Western Interconnection evaluate resource and transmission adequacy in a coordinated fashion through comprehensive wide-area system planning.[4]

1 California Governor's Office of Emergency Services. 2022. https://news.caloes.ca.gov/state-officials-sent-cell-phone-alerts-to-protect-public-safety-amidst-ongoing-record-heat-energy-grid-shortfalls/

2 National Integrated Drought Information System. 2023. https://www.drought.gov/news/summer-2023-review-look-back-drought-across-us-10-maps-2023-09-21

3 Jenkins, J.D., Farbes, J., Jones, R., Patankar, N., Schivley, G., "Electricity Transmission is Key to Unlock the Full Potential of the Inflation Reduction Act," REPEAT Project, Princeton, NJ, September 2022. DOI: 10.5281/zenodo.7106176

4 WECC. (2023). 2023 "Western Assessment of Resource Adequacy".

Recognition of these challenges has led to increased efforts to coordinate between BAs in their Resource Adequacy (RA) and transmission planning and in their operations. One such example is the Western Power Pool (WPP)'s coordinated planning for future load growth and weather impacts on resource availability their Western Resource Adequacy Program (WRAP).[5] The design of WRAP is intended to leverage the existing bilateral market structure in the West to develop a resource adequacy construct in which participants who are short of necessary supply can call on the resources of other participants who have surplus supply under extreme conditions.

In addition, and central to the motivation for this work are two proposals currently under development. (1) A multi-state stakeholder-led effort called the West-Wide Governance Pathways Initiative [6], initiated by regulators from five western states. This proposal seeks to create a new, west-wide, independently governed regional organization that oversees operation and evolution of the WEIM and EDAM, and potentially other grid services. Because an independent governance structure has the potential to attract additional participation to EDAM, this initiative proposes to reduce reliability risk across a wider footprint and be financially beneficial to its participants.[7] (2) A regional effort, led by Southwest Power Pool (SPP), an existing RTO located mostly in the Eastern Interconnection[8], that intends to offer a competitive wholesale market called Markets+, and is proposing the expansion of a Western RTO[9] that would operate alongside SPP's footprint in the Eastern Interconnection.

While other work has assessed the economic benefits of EDAM and Markets+ proposals in terms of reduced operational and consumer costs under normal operating conditions, it often has not focused on benefits from reliability improvements during extreme weather or challenging operational conditions. Here, we present analysis that illustrates the potential reliability benefits that could be achieved by greater cooperation across the Western Interconnection under stress conditions. We argue that such reliability benefits to people and communities in the West are at least as important as the economic benefits to electricity market participants.

Maintaining a reliable and sufficient electricity supply is not merely economically beneficial, failure to do so can and does have life threatening consequences. Hundreds died during winter storm Uri when the grid failed in Texas. With increasing system uncertainty, a larger footprint with greater resource diversity and operating flexibility can help to manage reliability risks across different regions in the West. In addition, a major disruption to BPS operations in the West is likely, fairly or not, to be blamed on the growing role of variable renewable generation – wind and solar – in western electricity supply. Such an event, were it to occur, might have widespread policy implications in other jurisdictions that have adopted or are considering adoption of renewable energy policies like California's and other western states.

5 WRAP. 2023. https://www.westernpowerpool.org/private-media/documents/WPP_WRAP_Interoperability_with_Markets_June_2023.pdf

6 West-Wide Governance Pathways Initiative. 2024. https://www.caiso.com/Documents/West-Wide-Governance-Pathway-Initiative-Overview.pdf

7 Energy and Environmental Economics (E3). 2023. *Western Markets Exploratory Group: Western Day Ahead Market Production Cost Impact Study.*

8 Southwest Power Pool. 2022. https://www.spp.org/media/1979/spp-markets-plus-proposal.pdf

9 Southwest Power Pool: RTO Expansion. 2021. https://www.spp.org/western-services/rto-expansion/

BACKGROUND: PLANNING AND OPERATIONS IN THE WESTERN INTERCONNECTION

The continental US contains three primary physical electricity grids, the Western Interconnection, the Eastern Interconnection and ERCOT in Texas. The Western Interconnection stretches from the West Coast into the Great Plains and from Western Canada to Baja California. It operates under the purview of WECC, which sets and enforces reliability and security standards for the region, FERC, which regulates transmission planning, investment and inter-state electricity markets, and numerous State utility commissions, which regulate many aspects of utility planning and investment. In addition, the North American Electric Reliability Corporation (NERC) tasked CAISO and SPP as the two reliability coordinators (RC)[10] in the West to assure the system complies with standards and security constraints. Today, in the Western Interconnection, 37 BAs[11] with widely varying governance are charged with assuring that demand for electricity within their geographies is instantaneously matched with supply of energy from electric generators. They keep the system in balance and manage the flows of electricity with neighboring BAs, since all of the Western interconnection's BAs have long relied on regional power exchanges to meet local demand.[12] This system balance is critical to the safe and reliable operation of the grid because at least for now, there is not widespread capacity to store electricity and so if demand and supply drift out of balance, voltage and current will also vary in ways that will cause the system to fragment and can lead to bulk power system outages like the multi-day blackout that occurred in 2003 in the Eastern Interconnection.

Beyond single-utility BAs, there are ISO and RTOs, which operate the transmission system through competitive wholesale electricity markets but do not own infrastructure such as generating units or transmission lines. The ISO structure is one that is designed to operate a certain region of the grid using an approach known as an organized wholesale market that generally consists of competitive auctions to determine which power plants provide services needed to assure grid reliability and wholesale electricity provision. An RTO, beyond an ISO's responsibilities, is also tasked with planning transmission upgrades and expansion in order to avoid line congestion during operation and assure there is enough interchange capacity in the system. In today's bulk power system operation and planning, an RTO is the most comprehensive regional governance structure since it has oversight of all phases including interstate transmission planning, in some cases, capacity expansion aligned with resource adequacy compliance within its footprint, and finally centralized unit commitment and economic dispatch. CAISO, while called an ISO for historical reasons, fills many of the roles of an RTO for the three large investor-owned utilities (IOUs) in California and a few smaller entities. Importantly for this discussion, it does not oversee power capacity expansion and resource adequacy in California or in any of the multi-state markets it currently operates or plans to operate. The rest of the entities that play the role of BAs in the Western Interconnection that are not part of an ISO/RTO structure are either traditionally

10 NERC. https://www.nerc.com/pa/rrm/bpsa/Pages/RCs.aspx

11 The Western Interconnection consists of 37 balancing authorities: 34 in the United States, 2 in Canada, and 1 in Mexico. https://www.eia.gov/todayinenergy/detail.php?id=27152#

12 WECC. *Western Assessment of Resource Adequacy*. November 2022.

operated utilities[13] that own generation, transmission, and distribution within their service territory or are Federal Power Marketing Administrations that own generation and transmission systems, providing wholesale power to other utilities.

All BAs, regardless of their structure, must ensure adequate planning for future electricity demand. In such planning, BAs conduct RA studies, develop transmission planning processes and incorporate state and federal policies such that their operation in future years will meet reliability requirements set by WECC and also be compliant with other policy goals such as Integrated Resource Plans (IRP) or Renewable Portfolio Standards (RPS). This planning can be challenging in that it requires consideration of the lengthy timelines for electric grid upgrades and generation and transmission expansions, including the planning, cost allocation, permitting, construction, and commissioning.

In operation, each BA procures the necessary resources to meet their load mainly through long-term contracts with generators within their territory and interchange of energy with their neighbors through forward contracts to purchase energy (sometimes referred to as bilateral contracts). In addition, in the West there are currently two regional energy imbalance markets: WEIM operated by the CAISO and the Western Energy Imbalance Service (WEIS) operated by SPP. Both markets facilitate trading of real time energy surpluses and deficits between BAs across the West. Energy Imbalance Markets are thus a means of trading excess energy after local needs within a BA have been met. Studies[14] and experience in the WEIM have shown that energy imbalance markets provide economic, reliability and environmental benefits to their participants.[15] Finally, CAISO's EDAM, a day-ahead market proposed by a number of western BAs and recently approved by FERC as a component of CAISO's tariff, is intended to extend the benefits demonstrated by the WEIM to a day-ahead market. SPP's Markets+, another day-ahead market under development, is also intended to integrate day-ahead and real-time unit commitment and dispatch.

Responding to Challenges in Planning and Operations

BAs across the West have faced increasing challenges in recent years in ensuring that they have sufficient resources to meet electricity demand, particularly during stress conditions. Electricity grid planning and operation are contending with three key challenges.

(1) Demand and resource availability are becoming harder to predict. Projections based on historic averages no longer accurately represent the impacts of climate change on electricity consumer behavior, as well as the effects of weather variations on both demand and resource availability. Buildout of distributed energy resources (rooftop solar, home energy storage, etc.) and electrification efforts (heat pumps, etc.) are key drivers in the increased variability of demand side forecasts. Climate change is leading to intensifying extremes, both in frequency and magnitude and in the breadth of impacted areas, leading to increased peak and net-peak demands across the West. The Government

13 Vertically integrated monopolies are responsible for generating, transmitting, and distributing electricity to their customers.

14 Extended Day-Ahead Market Participation Benefits Study prepared by The Brattle Group, Inc. https://www.brattle.com/wp-content/uploads/2024/01/Extended-Day-Ahead-Market-Participation-Benefits-Study.pdf

15 In CAISO, for example, energy procurement by utility-owned generation and forward contracts usually sums to be between 45-97% of the total need. The remaining 3-55% is acquired through wholesale markets coordinated in the day-ahead market (DA) accounting for roughly 95% of transactions and the real time (RT) or imbalance market that trades the remaining 5% to account for the mismatch in forecast and actual demand.

Accountability Office (GAO) suggests that FERC should act to introduce adequate and updated standards to account for the impacts of climate change.[16] In addition, the Summer Stack Analysis for 2022-2026[17] published by the California Energy Commission (CEC) in July 2022 concluded that *'grid reliability risks will persist through 2030 under the increased demand conditions experienced in 2020 and 2022 because of continued higher growth in electricity demand. These risks are compounded by the risk of coincident fires impacting generation and electricity imports to California .'* One of the key drivers of uncertainty in load growth is the proliferation of data centers. Some grid planners forecast that data center expansion could more than double load growth.

(2) The electric generating mix is in rapid transition. There is rapid growth of renewable capacity, like wind and solar, combined with retirement of thermal capacity, like coal. Also, short-term and long-term energy storage additions are creating new operating and planning strategies and capabilities for meeting demand in some jurisdictions. Planning has historically been driven by the peak demand hour in predominantly thermal dispatchable systems, where the system is at its highest strain, but in a high-renewables system, strain is dictated by a host of parameters, requiring a broader range of seasons, load levels and resource dispatch to be considered.

(3) The current patchwork of state and federal clean energy goals adds complexity in that each state has different incentives that influence operation and planning differently as well as having different levels of ambition and approaches to climate policy. In the Western Interconnection, these differences are particularly large, spanning from states with goals to fully decarbonize their electricity systems to states that hope to preserve the economic wellbeing of their coal mining industries and the power plants that purchase their output.

Since the 2020 and 2022 California heat events, the CEC and the California Public Utilities Commission (CPUC), have been required (as directed by SB 846) to provide reliability planning assessments, develop risk scenarios and update their operation and planning protocols. These efforts led to new interim transmission service and market scheduling priorities implemented in the summer of 2021, with a more durable approach implemented in 2024 that better recognizes the contracted supply, available transmission and resource adequacy relationships. The CEC and CPUC are also in the process of developing climate-informed load forecasting approaches that take account of climate change impacts on extreme conditions in the West.

In the Western Interconnection, all BAs operate with interchange of electricity; system efficiency, economic benefits of participating in wholesale markets, and ultimately the need to assure that supply is sufficient to meet demand dictate times when a BA becomes a net exporter or net importer. However, when the system is most stressed in the presence of extreme weather events that span across a large footprint, availability of resources in wholesale markets may be compromised, thus reducing imports and increasing the risk of not meeting demand. In such situations, operators in each BA make decisions based on imperfect information and have to rely on best practices and operator experience to overcome challenges in real-time. This uncertainty in the system poses a higher risk of failing to meet reliability and security standards and potentially leads to local or widespread power outages.

16 GAO. (2021, Mar 05). U.S. Government Accountability Office. Retrieved from https://www.gao.gov/products/gao-21-346

17 https://www.energy.ca.gov/publications/2021/2022-summer-stack-analysis-update

The key operational advantage of ISO/RTO organized wholesale markets is to create day-ahead and real time transparency into the availability, price, and deliverability of energy resources across a multi-utility footprint. Coordination and optimization of operations under stress conditions within an ISO/RTO footprint is accomplished via computer algorithms that solve for the complex problem of meeting demand across the footprint at least cost using available supplies. This approach allows for greater visibility into which resources are actually available and what an optimal dispatch of resources is under stress conditions. By contrast, a more fragmented system of smaller BAs with incomplete information and optimization protocols focused on their BA rather than the region may lead to suboptimal decisions both in the day-ahead and the real time operational time frames. Particularly when resources are short, this visibility of available resources across a footprint can be helpful to maintaining reliability for bulk power system operations. Two states, Colorado and Nevada have requirements for their investor-owned utilities to join an RTO in the near future.[18]

In the next section, we evaluate how this shift – from a more fragmented structure of many smaller BAs that each meet supply-demand balance according to their regional or state/local resource adequacy requirements along with bilateral contracting – compares to an approach with a progressively larger cooperation footprint.

18 Colorado S.B.072 and Nevada S.B.448.

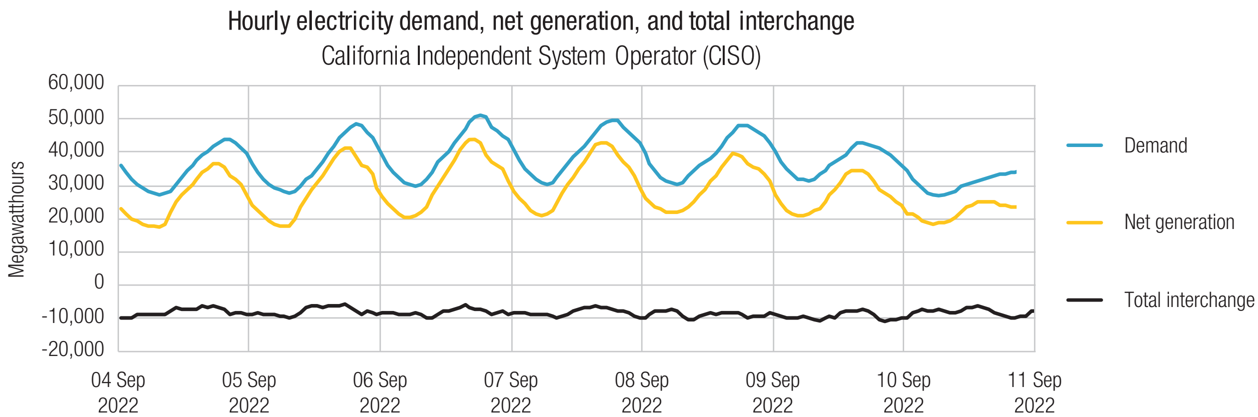
CASE STUDY: A SIMULATION OF THE WESTERN INTERCONNECTION FOR ONE MONTH OF OPERATION UNDER STRESS CONDITIONS

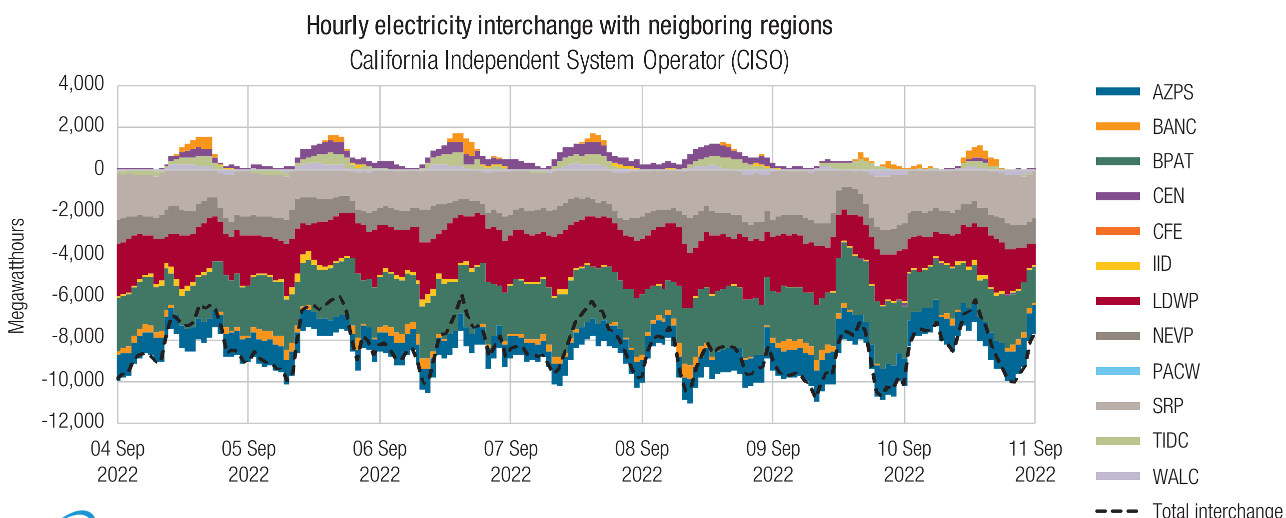
This study evaluates shifts in grid operations, the utilization of generation, imports, and exports, as we assign different ISO/RTO footprints in the West. We do this to evaluate the potential benefits to operational reliability under grid stress conditions created by extreme heat through creation and expansion of a western ISO/RTO. We benchmark our simulated stress conditions to the conditions experienced in September 2022 in California, when CAISO recorded record peak demand. Figure 1 (top panel) shows total CAISO grid demand (blue), net generation (yellow) from generating units that are managed by a BA or whose operations are visible to a BA, and total interchange (black) with neighboring BAs on the record peak demand day of September 6, 2022 and surrounding days. To avoid losses, CAISO imported energy, on balance, from neighboring BAs to make up the difference between net generation and total demand. Figure 1 (bottom panel) shows the decomposition of energy interchange with neighboring BAs, showing that there were still exports during periods of high demand.

The stress conditions set in the case study that follows are derived from the extreme conditions experienced during this event, but with stress levels sustained throughout a month-long operating horizon. We acknowledge that a month-long, widespread event is unlikely, yet the intention behind this study is to provide insight into a worst-case scenario and how different levels of cooperation might fare against such a stressor. We run a simulation of the entire Western Interconnection during one month of operation at three different levels of compounding stresses. Each stress scenario is then modeled under three cases representing different levels of operational integration and cooperation in the Western Interconnection.

Figure 1. Stress event during Sep 2022 heat wave in CAISO (referred as CISO in the figure) territory.

Total Interchange: negative interchange values indicate net inflows, and positive interchange values indicate net outflows. The top graph shows the total demand, the generation and the total interchange. The bottom graph shows the distribution of energy interchange with neighboring BAs.





eia Source: U.S. Energy Information Administration, Form EIA-930, 'Hourly and Daily Balancing Authority Operations Report'

Simulating reliability impacts with power system optimization models is challenging because these models generally assume perfect information to optimize dispatch across all western BAs. In the real world, especially during stress events, system operations can diverge substantially from the optimal outcome due to incomplete information, risk aversion by individual BAs, and other factors. Because of this challenge in simulating stress conditions, we interpret our results as illustrative and directional rather than a precise estimate of the reliability benefits of a multi-state ISO/RTO. Nevertheless, we show that growing the footprint of an ISO/RTO in the West has the potential to substantially reduce risks to reliability under extreme heat scenarios derived from the September 2022 California heat event. In other words, by expanding organized wholesale markets beyond the current EDAM partners, our work suggests that western BAs can reduce the risks of unserved energy and rolling blackouts. This work thus complements earlier work on economic benefits and adds an additional dimension to the ongoing cooperation regarding improved coordination of electricity operations in the West.

Model and Study Design

All simulations are done using Energy Exemplar's PLEXOS CloudUI services and their 2024 WECC Zonal dataset.[19] This study is done using a zonal model that runs a production cost optimization to dispatch resources to meet demand in each zone, given physical and financial constraints for emissions, generators, fuels, transmission lines and wheeling rates. Fuel supply for all resources is assumed available, including predetermined wind, solar and hydro profiles. This model's representation of the Western Interconnection is divided into 34 BAs, shown in Figure 2. Note that CAISO, even though it is a single BA, in this model, is subdivided into its 4 subregions[20]. We recognize and acknowledge the limitations of using a zonal rather than a nodal model for evaluating grid operations. Zonal models cannot be relied upon for precise quantification of changes to operations. However, in this case, because of the intent to provide insight into the reliability impacts of progressively larger organized wholesale markets rather than to precisely quantify these benefits, we believe use of a zonal model is both adequate and appropriate.

Figure 2. 34 simulated BAs in the WECC.[21] (Note: CAISO is subdivided into its 3 IOUs and VEA)

To assess reliability and energy interchange, we divide the Western Interconnection into different operating subregions in the three geographic cases we model, as follows (see also Figure 3). The subregions in cases 1 and 2 are considered operating islands, cutting any energy transactions at the seams. We understand this assumption is an extreme condition that would assume inability to rely on neighboring BAs outside the subregion and disregards the already existing market participation in wholesale markets or long-term contracts. This assumption is intended to

19 Energy Exemplar. (2024). 2024 PLEXOS WECC Zonal Release Notes; Energy Exemplar's 2024 PLEXOS WECC Zonal dataset; The case studies were run using PLEXOS Engine Version 10.0 R04, virtual machine 32 Core – 256 GB RAM – 1200 GB Disk.

20 CAISO participating utilities and boundaries. https://westerngrid.net/wcea/wp-content/uploads/2016/07/governance-figure1-CAISO-util.png

21 The boundaries and shapes are an approximation the actual footprints and are only used for illustration purposes modified from WECC 2017 map. https://www.wecc.org/Administrative/Balancing_Authorities_JAN17.pdf

simulate an operational fragmentation that represents the increased value of information about available resources and willingness to trade resources between regions during stress events. We are intentionally maximizing the frictions in the system during an extreme event to highlight how cooperation enhances reliability. But we emphasize that our assumptions mean that our results should be interpreted as directional and illustrative rather than as precise estimates.

Case 1. Region A (blue) is an ISO/RTO footprint based on the members of the EDAM operated by CAISO. Region B (orange) represents the rest of the Western Interconnection.

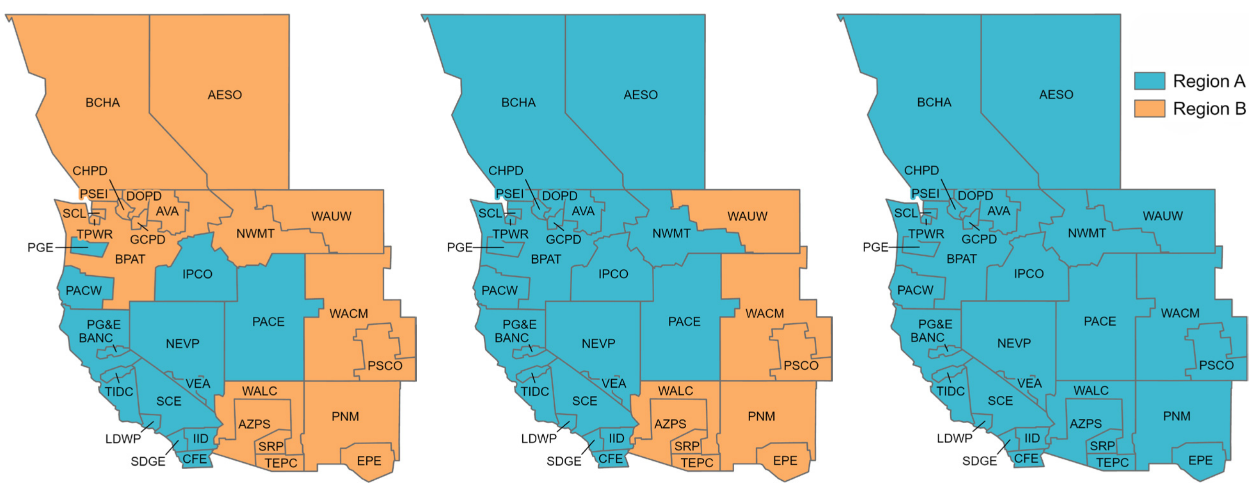
Case 2. Region A (blue) adds most of the Pacific Northwest to this ISO/RTO footprint. This addition includes various BAs currently in the WPP, some of which are already active participants in WEIM. It also includes some BAs that have indicated a preference for participation in the Markets+ day-ahead market under development by SPP. Region B (orange) represents the rest of Western Interconnection encompassing Arizona, New Mexico, Colorado, and parts of Wyoming and Montana.

Case 3. West-wide ISO/RTO, with no subregions. Imports and exports have no restrictions other than the zonal transmission constraints. This footprint is the 2024 PLEXOS WECC Zonal dataset system modeled without modifications.

For cases 1 and 2, each BA is either in subregion A or B, detailed in Appendix A. Note that the cases do not represent the EDAM and other markets precisely but are rather an approximation of the possible participation of BAs in a future ISO/RTO. The intention of our study is thus to illustrate how growth of regional cooperation is likely to impact risks to reliability under stress conditions, but not to quantify the exact benefits.

Figure 3. Geographic cases.

Case 1 and 2 are divided into two subregions: A (blue) and B (orange). Case 3 is represented as a single West-wide ISO/RTO.



CASE 1 CASE 2 CASE 3 West-wide ISO/RTO

These (sub)regions operate like single entities composed of the sum of the generation, load and resources of the BAs that comprise them. We limit the interchange of electricity at the seams of each subregion, such that regions can only satisfy their demand with their internal resources, without imports across these seams. Disallowing energy exchange between subregions is a scenario considered in the WECC's WARA,[22] where the whole West is divided into 5 subregions and analyzed separately including a 'no imports' case study. Although this imposition is an extreme assumption that disregards bilateral contracts that do exist across these seams and diverges from normal operations, during stress events, as mentioned previously, energy imports and exports especially among BAs that are not in the same wholesale power pool become scarce, especially under stress conditions. We acknowledge that the strictness of these assumptions in particular shows a worst-case and improbable scenario and could be further relaxed by incorporating historical bilateral contracts.

The model also does not simulate the many daily decisions made by operators with imperfect information. The optimization also does not include market structures, bilateral contracts or storage charge/discharge algorithms for arbitrage. Given this framework, modifying the geographic footprint of a subregion will ultimately impact coordination among BAs in operations and when addressing reliability and resource adequacy challenges under stress conditions.

The stress levels, detailed in Table 1, are set to represent compounding effects including climate-related extreme events (heatwaves, wildfires, drought) and load growth. Stress level 1 (baseline) focuses on September 2022 load data, as it is intended to benchmark against the stress event experienced in California in that month. For stress levels 2 and 3, similar to the Summer Stack Analysis for 2022-2026[23] proposed by CEC, we increase loads in each BA by 15% and 40% above baseline as a proxy for stress as shown in Figure 4. Interconnection between BAs are transmission lines based on historical five-year running average energy flows, and there are no builds of new generation units or retirement of units. Drought conditions are based on historical data created from the lowest available hydro year in the WECC over the past 22 years. Generator outages are based on historical 2022 outages reported by EIA.

22 Western Assessment of Resource Adequacy. 2022. https://www.wecc.org/wecc-document/5436

23 https://www.energy.ca.gov/publications/2021/2022-summer-stack-analysis-update

Table 1. Stress Levels

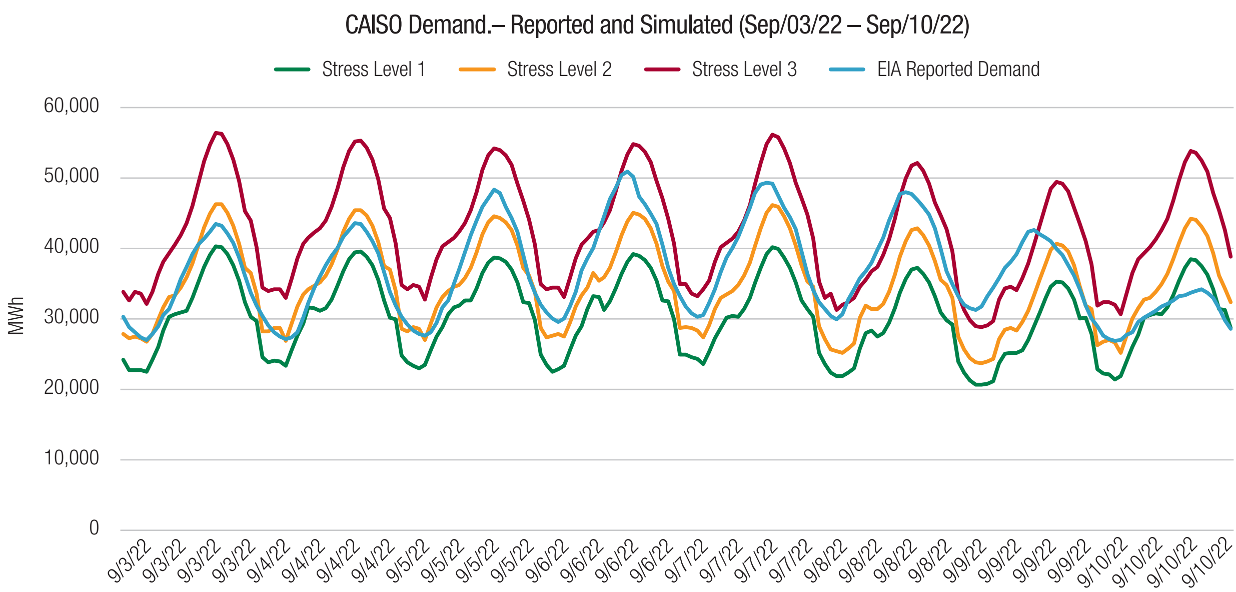
Case	Demand	Other conditions
Stress level 1	baseline	Drought year, Generator outages
Stress level 2	15% above baseline	Drought year, Generator outages
Stress level 3	40% above baseline	Drought year, Generator outages

Stress level 1 (Baseline) is a construct from 2024 WECC Zonal PLEXOS dataset which is based on historical and forecasted profiles from the 2032 Anchor Data Set (ADS) along with EIA, FERC-714 filings and other resources. The information for baseline load, generation and the simulation as a whole is taken from the month of September 2022 as represented in the dataset used.

Stress level 2 stresses the system to 15% above the baseline case, a standard capacity reserve margin.

Stress level 3 stresses the system to 40% above baseline, representing demand behavior similar to but somewhat higher than the increase in demand during the Sep 2022 heatwave event in California, shown in Figure 4.

Figure 4. Example of load at the 3 stress levels and reported (Example: CAISO BAs)



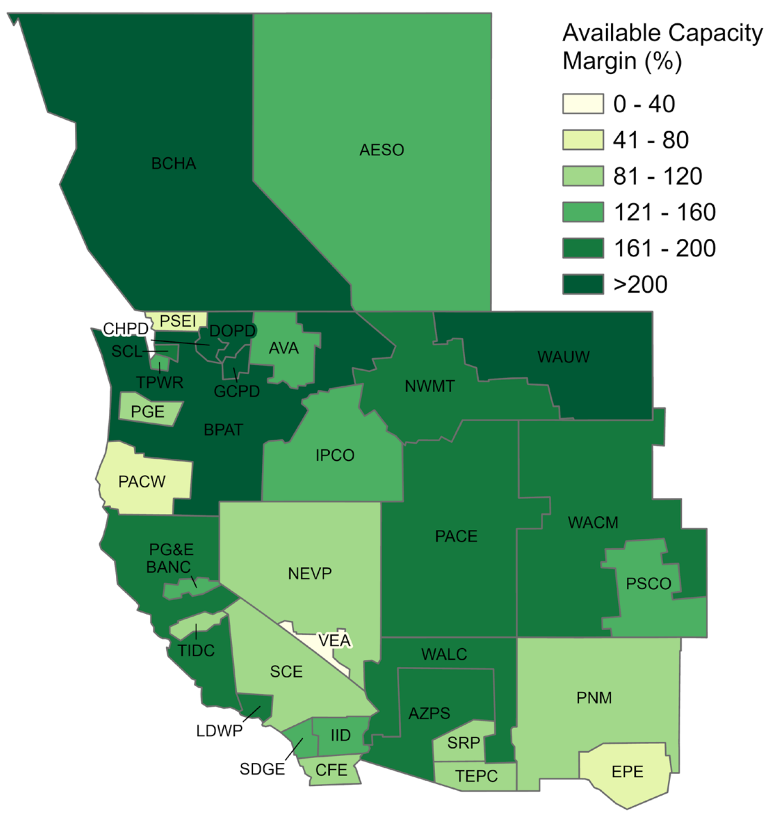
Simulation Results

As a starting point to provide context for the results that follow, Figure 5 shows the available generating capacity margin (%) for each BA as represented in the model, expressed as a function of generating capacity vs. peak load. Available generating capacity in a given BA is the sum of all generators, including operating constraints, capacity factor, ratings, and resource availability.

$$\text{Available Capacity Margin (\%)} = 100 \times \frac{\text{Available Capacity}}{\text{Peak Load}}$$

The higher (darker green) values indicate BAs where generating capacity exceeds peak load. Values lower than 100% suggest that BAs must rely on imports from other BAs to satisfy their peak demand. This shows the baseline operations in our model; real available capacity, especially during a stress event, may differ from what is modeled.

Figure 5. Available Capacity Margin (%) for baseline



As described above, we run a simulation of the entire Western Interconnection during one month of operation for each of our three geographic cases representing different levels of cooperation and three stress scenarios representing different levels of stress. Table 2 presents three summary metrics for each geographic case and stress scenario. The first two are also presented in Figure 6.

1. **Hours at Risk (%):** The percentage of hours during the simulation month when the system is at or above a "risk threshold" indicating system stress. The risk threshold is determined by the value of lost load (VoLL), a value embedded in the model's dataset[24] and used without modification, in this case 550 $/MWh for all BAs.
2. **Unserved Energy (%):** The percentage of hours during the simulation month in which there was unserved energy (USE). USE indicates a loss of load event—demand at the zonal level (BAs) that was not provided by available generation or transmission resources. Reasons for this include a shortfall in generation locally and in neighboring BAs, loss of transmission availability, or prices above VoLL.
3. **Unserved Energy (GWh):** The magnitude of USE across the system during the simulation month, in Gigawatt hours.

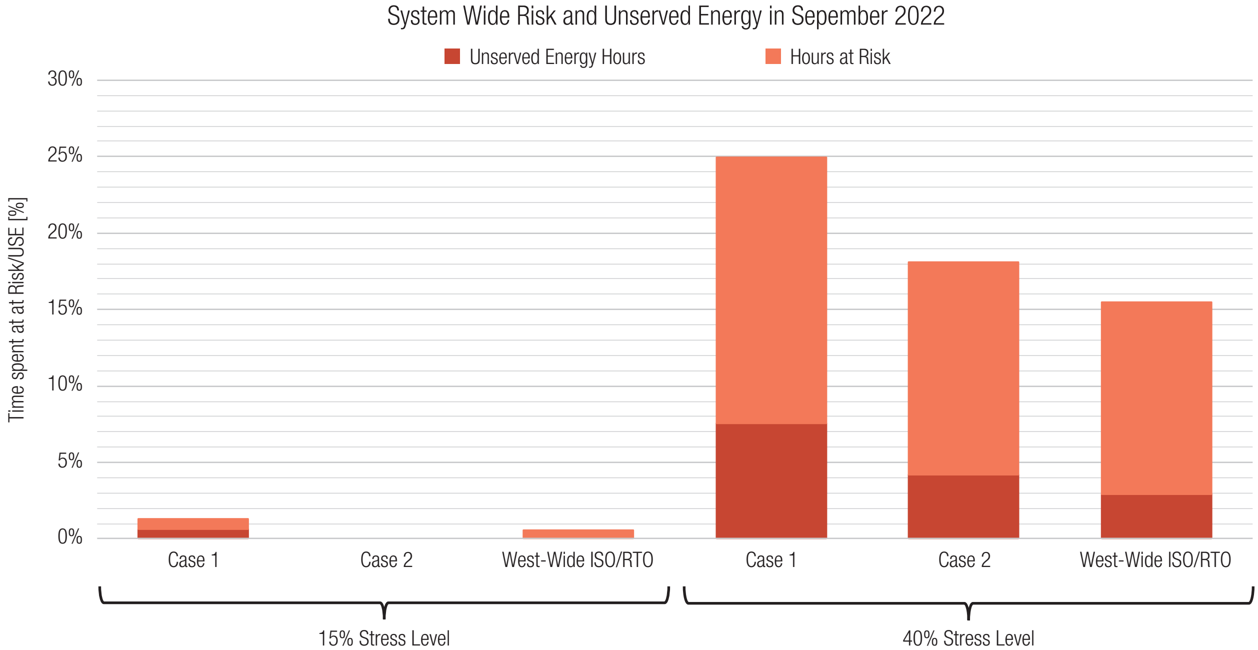
Table 2. Monthly System Wide Risk and Unserved Energy

	Monthly System-Wide Risk and Unserved Energy								
	Case 1			Case 2			Case 3: West-Wide		
	Hours at Risk	USE	USE	Hours at Risk	USE	USE	Hours at Risk	USE	USE
	%	%	GWh	%	%	GWh	%	%	GWh
Base load	0%	0%	0	0%	0%	0	0%	0%	0
15% Stress	1.30%	0.64%	22.5	0%	0%	0	0.54%	0%	0
40% Stress	24.93%	7.55%	1,901	18.13%	4.18%	1,243	15.46%	2.92%	877

These results illustrate the benefits of expanding cooperation across the Western Interconnection. With 15% stress being imposed on the whole system, the difference in hours at risk and USE across different footprints is less evident, as each (sub)region largely has enough capacity to overcome a level of stress comparable to running the system at the reserve margins. Notably, the 2022 event indicated that these reserve margins may not reflect the full scope of potential peak demand. Under an increased stress level of 40%, however, the benefits of cooperation and expanded energy interchange possibilities are clearer. We observe a major decrease (from 25% to 15%) in systemwide hours at risk following expansion of an ISO/RTO from the EDAM footprint to the entire Western Interconnection. Simulated USE is also more than cut in half (from 1901 to 877 GWh). As discussed previously, a month-long, widespread 40% stress event is unlikely, yet the intention behind this study is to provide insight into how different levels of cooperation might fare against such an extreme stressor.

24 Energy Exemplar's 2024 PLEXOS WECC Zonal dataset

Figure 6. Monthly System Wide Risk and Unserved Energy



System-level results tell one part of the story; but not all BAs bear the same level of risk. Even within the same cooperating (sub)regions, different BAs have different availability of generation resources and transmission capacity connecting to other neighbors, as well as different resource mixes. Some rely on fossil fuels as their bulk generating fleet, while others are more reliant on renewable resources. These embedded characteristics differentiate each BA's ability to reduce risk and prevent unserved energy.

CONCLUSIONS

This study provides insight into the electricity reliability benefits of greater market and operational integration and coordination in the Western Interconnection. We show that larger footprints for a single ISO/RTO create larger reliability benefits during extreme events. Since these events are increasingly likely due to climate change and the evolution of both energy supply and demand in western BAs, the value of cooperation is greater today and in the future than in the past. Restructuring electricity markets, grid operations, and grid planning into a single West-wide ISO/RTO requires careful study and resolution of multiple issues, including governance, cost allocation, stakeholder participation, and incorporation of state policy goals. Our focus here is on reliability and we defer to other studies for the evaluation of other benefits and risks.

Simulating reliability impacts with power system optimization models is challenging because these models assume perfect information to optimize dispatch and constant frictions in trading energy between BAs even though the reality in wholesale markets is that information is imperfect and frictions can increase dramatically during stress events. In other words, the models behave as if an ISO/RTO exists, with some limited economic frictions, but in the real world, especially during stress events, system operations can divert substantially from the optimal outcome. As a result of this modelling challenge, we are cautious in interpreting our results and view them as illustrative and directional rather than a precise estimate of the reliability benefits of a larger, regional day-ahead market and operational structure. Nevertheless, we show that growing the footprint of an ISO/RTO in the West has the potential to substantially reduce risks to reliability under extreme heat scenarios. By expanding an ISO/RTO framework beyond the current EDAM footprint, our work suggests that western BAs can substantially reduce the risks of rotating outages. This work thus complements earlier work on economic benefits and adds an additional dimension to the ongoing efforts to increase integration of electricity operations in the West.

Outside the scope of our work, but complimentary to it, is the need for a probabilistic analysis to show the current and future likelihood of system wide high intensity/long duration stress events under various climate change scenarios. Work of this nature is underway for California, conducted by the CEC. Further study examining the full complement of western BAs is crucial to understanding the full scope of the problem both today and as the West gets hotter and drier. The greatest challenges for the Western Interconnection occur when multiple areas experience extreme heat simultaneously and so are unable to rely on each other for normal and especially increased levels of energy imports. As illustrated in our case study, these challenges are most pronounced in the context of lower hydro availability due to drought, also a feature of recent experience as well as climate change projections.

Day-ahead and real-time markets are crucial mechanisms that allow BAs to match supply and demand within their territory but current approaches to handling extreme events that impact multiple BAs have real limitations. When extraordinary events impact a BA's generating capacity and their trading neighbors suffer the same impact, a reliance on imports to avoid rolling blackouts is put in jeopardy. The results from the case study show that expansion of an ISO/RTO footprint is one way to substantially lower risk of unserved energy for customers. Our simulations show, qualitatively, how creation of a multi-state market can reduce risk, and that the bigger the market, the greater the risk reduction achieved. There are also other ways to reduce these risks and we would be the first to emphasize that all avenues for preserving bulk power system reliability in the face of the current challenges should be pursued.

States in the Western Interconnection are at the forefront of the energy transition. Large changes to systems as complex as the integrated yet massively distributed machine we call the Western Interconnection will always create some degree of risk. The West and in particular California play an important role in demonstrating that a high renewables, low emissions, and high reliability grid is achievable. In addition to the normal reasons for ensuring bulk power system reliability, policymakers should take all feasible steps to ensure that problems with reliability do not occur because such problems, unlike in Texas after winter storm Uri, are likely to be blamed on renewables. If such a western outage were to occur, this narrative would be likely to slow national and global progress towards zero carbon resources, even if the fault is misattributed.

In the end, the decision to pursue key changes to governance or markets, operations and planning that are beyond the scope of this work – especially a fully independent governance structure for a multi-state ISO/RTO – needs to be made by policymakers after considering a wide array of benefits and risks. This paper has shown that the benefits extend beyond simply economic ones – redistributing gains and losses between particular stakeholders in particular BAs – and extend to the reliability of the bulk power system in the West. That is not terribly surprising given that the physical system we inherit was built with deep cooperation and integration in order to assure reliability. Deepening that decades long collaboration by further integration of market structures and operations allows us to reduce risk of failure as we transition to a hotter, drier, but lower carbon future. This can't be the only consideration in discussions around creation of an ISO/RTO, but it is a consideration that should be central to the ongoing discussions and decisions of energy policymakers.

LIST OF ABBREVIATIONS

ADS	Anchor Data Set
BA	Balancing Authority
BPS	Bulk Power System
CAISO	California Independent System Operator
CEC	California Energy Commission
CPUC	California Public Utilities Commission
EDAM	Extended Day-Ahead Market
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
GAO	Government Accountability Office
GWh	Gigawatt hour
IOU	Investor-Owned Utilities
ISO	Independent System Operator
NERC	North American Electric Reliability Corporation
RTO	Regional Transmission Organization
SPP	Southwest Power Pool
USE	Unserved Energy
VoLL	Value of Lost Load
WECC	Western Electricity Coordinating Council
WEIM	Western Energy Imbalance Market
WEIS	Western Energy Imbalance Service
WPP	Western Power Pool
WRAP	Western Resource Adequacy Program

APPENDIX A: BALANCING AUTHORITIES

Table 3. Balancing Authorities; participation in current market structures and simulated case studies

		Markets				Case Studies		
Balancing Authority	**Abrev**	**WEIM**	**WEIS**	**EDAM**	**Markets+**	**Case 1**	**Case 2**	**Case 3**
Alberta Electric System Operator	AESO					B	A	A
Avista Corporation	AVA	X				B	A	A
Arizona Public Service Company	AZPS	X			X	B	B	A
Balancing Authority of Northern California	BANC	X		X		A	A	A
Bonneville Power Administration – Transmission	BPAT	X			X	B	A	A
British Columbia Hydro Authority (Powerex)	BCHA	X				B	A	A
PUD No. 1 of Chelan County	CHPD				X	B	A	A
PUD No. 1 of Douglas County	DOPD					B	A	A
El Paso Electric Company	EPE	X				B	B	A
PUD No. 2 of Grant County	GCPD				X	B	A	A
Idaho Power Company	IPCO	X		X		A	A	A
Imperial Irrigation District	IID					A	A	A
Los Angeles Department of Water and Power	LDWP	X		X		A	A	A
Comision Federal de Electricidad	CFE					A	A	A
Nevada Power Company	NEVP	X				A	A	A
NorthWestern Energy	NWMT	X				B	A	A
PacifiCorp East	PACE	X		X		A	A	A
PacifiCorp West	PACW	X		X		A	A	A
Pacific Gas & Electric Company	PGAE	X		X		A	A	A
Portland General Electric Company	PGE	X		X		A	A	A

		Markets				Case Studies		
Balancing Authority	**Abrev**	**WEIM**	**WEIS**	**EDAM**	**Markets+**	**Case 1**	**Case 2**	**Case 3**
Public Service Company of Colorado	PSCO				X	B	B	A
Public Service Company of New Mexico	PNM	X				B	B	A
Puget Sound Energy	PSEI	X			X	B	A	A
Salt River Project	SRP	X			X	B	B	A
Southern California Edison	SCE	X		X		A	A	A
San Diego Gas & Electric Company	SDGE	X		X		A	A	A
Seattle City Light	SCL	X				B	A	A
City of Tacoma, Department of Public Utilities	TPWR	X			X	B	A	A
Turlock Irrigation District	TIDC	X		X		A	A	A
Tucson Electric Power Company	TEPC	X			X	B	B	A
Valley Electric Association	VEA	X		X		A	A	A
Western Area Power Administration, Colorado-Missouri Region	WACM		X			B	B	A
Western Area Power Administration, Lower Colorado Region	WALC	X			X	B	B	A
Western Area Power Administration, Upper Great Plains West	WAUW		X			B	B	A

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